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Before major water treatment facilities are designed or built, pilot plant studies are often conducted. These studies need to be planned and carried out properly if they are to provide the desired benefits. Pilot plant studies may be conducted to evaluate treatment or operating alternatives, or to evaluate theories or concepts of operation and treatment. Data needs for pilot studies can include water quality data and cost data. An appropriate range of conditions, including extremes that may be expected, should be evaluated. Equipment used in pilot plants should be of an appropriate design, suitable for scale-up and reasonable to operate. Data collection should not be excessive, but documentation of methods and results must be adequate. Quality control and quality assurance are very important. Data from the project should be reviewed frequently to ascertain that the study is accomplishing the desired goals. After pilot operations are completed, final analysis of data and preparation of a clear, understandable report are the concluding tasks.

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PILOT PLANT STUDIES - FROM STUDY PLANNING TO PROJECT IMPLEMENTATION

Gary S. Logsdon
Research Sanitary Engineer
Drinking Water Research Division, MERL, USEPA

INTRODUCTION

Before major water treatment facilities are designed and built, pilot plant studies are often conducted. Engineers attempt to evaluate treatment alternatives by using small treatment units (pilot plants) in hopes of achieving important cost savings when full-scale construction occurs. Trussell (1) presented a suggested range for pilot plant costs based on the estimated construction costs for full-scale plants. His figure is redrawn and shown as Figure 1. The potential for saving money on construction is greater on large projects, so extensive preliminary studies may sometimes be conducted.

When planning a pilot plant study consider: 1) the purpose of the study, 2) the data needed, 3) the kinds of equipment to be used, 4) data collection procedures, 5) documentation of equipment used and work done on the project, 6) periodic data analysis during the study, 7) final interpretation of the data, and 8) the final report to describe the work and show how the findings could be implemented on a larger scale.

PURPOSE OF STUDY

Pilot plant studies are conducted for a variety of reasons. Alternative treatment processes may be investigated, if construction of facilities is contemplated. At existing facilities, different operating techniques may be tested in a pilot plant before the change is made in the full scale plant.

Pilot plant investigations may be used to evaluate process theories or concepts. Theory can provide the basis for trying a process or an operation modification. Theory also gives direction with respect to the kinds of data to collect. For example, size and shape of media are important factors in water filtration theory, so these data would be needed in a filtration study. Measurement of energy imparted to the water in a flocculator would be important in an evaluation of flocculation.

DATA NEEDS

The kinds of data needed vary from study to study. A complaint sometimes heard is that persons who plan/conceive pilot plant studies (often engineers) request every conceivable analysis from the chemists and biologists who must do the laboratory work. This may indicate that the person making the request does not understand what factors are important in achieving the primary purpose of the study. An adequate amount of data should be collected, but because of the expense of sample collection and analysis, and of data manipulation for interpreting results, excessive data collection should be avoided and analytical staffs should not be overburdened.

Water quality data needs are varied. Information should be obtained on raw water or on water quality before some modification, and on treated water

quality, or the quality of water after some process modification. During the pilot plant study, engineering information on flows, feed rates, pressures, contact times, equipment performance, and other factors would be collected. Numerous kinds of miscellaneous data may be of use also. Weather observations, river flows, lake or reservoir levels, industrial or municipal waste discharges, changes in equipment at the treatment plant, or repairs and maintenance in the distribution system might have impacts on various sorts of pilot studies. The precision and accuracy required for the data should be carefully considered so that the most economical methods can be used to obtain the necessary data.

When pilot work is done, adequate data related to costs should be collected so that estimates of the cost of a full-scale system can be made with accuracy. Data will be needed for capital costs; for labor hours per day, week, or month; for materials on a continuing basis (e.g. corrosion inhibiting chemicals, or coagulant chemicals, or chemicals for pH adjustment); and for energy consumption. Energy use and chemical use may be related to flow and to aspects of raw water quality, and this should be determined in the pilot plant work, if possible.

During the pilot study, data should be collected for performance during typical conditions as well as during extremes of good and bad raw water quality. The influence of seasonal factors is often important and should be evaluated if possible. Pilot plant results may be influenced by temperature, growths of algae and diatoms, seasonal or unusual episodes of runoff and turbidity, and by water demand (in the case of corrosion studies done in a portion of the distribution system). Pilot operations also should include normal plant variations of flow that normally exist and affet detention times and hydraulic loading rates.

Pilot plant work should go on for a long enough time period to obtain data on the extreme conditions that may be anticipated, but budget constraints will usually prevent excessively long studies. Performing repeated tests for month after month may not be necessary when test results can be obtained in a day or two, but tests should be performed on an intermittent basis when conditions warrant. An example of this approach would be rapid rate filtration studies. Hudson (2) suggested that periodic short term studies about two weeks long conducted at critical times may be sufficient. On the other hand, one slow sand filter run might last from two to four months, and an evaluation of corrosion inhibitors might last for six months. In the latter studies, the treatment process must be continuous over a long period of time, but the level of effort for the persons doing the study would not be very intense.

When pilot plant studies are performed for the purpose of investigating natural phenomena, the engineer is unable to control the situation, but rather must wait for events to happen. For example, when the pilot plant studies of water filtration for asbestos fiber removal were conducted at Duluth in 1974, one important aspect of the work was filtering water when Lake Superior was covered with ice, or just after the breakup of ice cover in spring. Coagulating and flocculating very cold water is difficult, so this needed to be studied. The effects of high turbidity from the occasional storms on Lake Superior also

needed to be investigated, but no really severe storm occurred during the April-through-September period of pilot plant operation. In this project, four pilot filters were evaluated. The continuing expenses for equipment and personnel and the urgent need for pilot plant data that could be used for design of a filtration plant resulted in operation of the pilot filters on a continuing basis rather than on the intermittent approach as described by Hudson.

After funds were exhausted, the pilot plant work was completed, and equipment was removed from Duluth, a very severe storm occurred on Lake Superior, raising the turbidity and amphibole fiber count to values much higher than any encountered in the study. Although questions were raised concerning the ability of the proposed filtration plant to deal with storm events, when severe storms occurred after the plant had been built, results of turbidity and asbestos monitoring showed that the treatment plant could cope very well with higher turbidity and fiber counts in the raw water.

Other examples of pilot plant studies that were somewhat frustrated by the vicissitudes of nature are filtration studies conducted in cooperation with Erie, Pennsylvania and with the Indianapolis Water Company. In both cases, water filtration experiments were carried out in the summer to investigate effects of algae, but no big algal bloom took place during the year of the pilot study. This sort of happening could not be predicted in advance.

Careful control of variables is essential in pilot work. Change only one variable at a time and run long enough to evaluate its effect. Variables that experience or theory indicates are important are the ones to evaluate. Finally, be sure that the variables evaluated and the range of these variables would be practical if applied full scale. Studies of coagulation with polymer doses exceeding the recommended limit would be of little use. Also, few water utilities would install rapid mixers having the mixing intensity of a food blender found in many home kitchens. The reader can probably think of other examples of this sort.

EQUIPMENT

Selection of equipment for the study is important. It should be of an appropriate design that can be scaled up. Although some pilot plant studies may lead to development of new equipment, if existing equipment is evaluated, engineers have a greater assurance that full scale equipment will be readily available. Equipment selected for testing should be reasonable to operate, in terms of energy consumption, manpower requirements, and continuing material costs.

Equipment should be an appropriate size for the kind of data collected. Pilot filters used at Chicago in the 1930's ranged in size from 2 inches to 100 square feet, according to Hudson (p. 237) (2). For filter backwashing studies, use filters large enough to fluidize naturally during backwash to eliminate questions about size effects on filter behavior. For ion exchange, activated alumina, and GAC column studies, the columns should be large enough to eliminate wall effects - ID 50 or 60X granule size or larger. Columns need to be big enough to backwash if this is necessary, but small enough to exhaust the column in a reasonable time or with a reasonable volume of water.

An indication of the capability of the pilot plant to model an existing full-scale plant for which changes are contemplated can be obtained by operating the pilot plant in the same way as the full-scale plant first. If both produce water of a similar quality, the engineer will have more confidence when decisions are made about full scale implementation of a proposed process that worked well in the pilot plant.

DATA COLLECTION

Data collection procedures will vary according to the type of data being collected and the frequency of analysis. Collection may be done manually or with continuously recording equipment. When choices are available, manpower costs and schedules for data collection should be compared to cost of purchase of recording equipment.

Sample collection, preservation, and analysis are very important. Samples must be identified properly. Samples must be preserved in ways that maintain sample integrity, and they need to be analyzed as soon as practical after collection. One of the unforeseen problems in the Duluth pilot plant study was caused by selection of a Canadian laboratory for transmission electron microscope analysis of asbestos fibers in water. The laboratory was one of only a few in the United States and Canada that had the analytical capability and could process the large number of samples that would be collected. Large delays in obtaining data occurred, so that fiber count data were available usually no sooner than one or two months after sample collection. Part of the delay was expected as a result of the work load at the laboratory, but the long times required for water samples to pass through customs at the U.S.-Canadian border frustrated the pilot plant enginers throughout the study. The methods used should be from Standard Methods when possible. A plan for quality control and quality assurance should be prepared and followed. Analytical methods should be checked and verified by using knowns and standards, spiked samples, and by conducting repeated analyses of some samples.

DOCUMENTATION OF PROJECT

Documentation of the project is very important, for without adequate documentation, preparation of a project report is impossible. Processes and equipment need to be thoroughly described, with complete diagrams, complete narrative descriptions, and photographs showing important features.

Adequate records are essential for quality assurance. Sample collection must be carefully documented so that no confusion arises over the samples later. Date and time of collection, source of sample, name of the sample collector, and any noteworthy circumstances need to be included on the sample tag. Analytical methods can be described by referring to Standard Methods or some other published method. If a published method is not used, a complete description of the method should be included in the project report.

Results should be kept in a file system that is easy to use, where data cannot become lost. Do not hastily write laboratory or plant data on paper towels or something that looks like scrap or waste paper. All results should be entered in official data books that will be kept after the project is completed. An acid test for documentation can be applied, to be sure record keeping is adequate. Ask the following:

If your engineer, chemist, pilot plant technician, or operator left your pilot plant program tomorrow, could you bring in another person who could review the existing records and continue the study with a minimum of transition difficulties? If you could continue your project with new personnel and write the final report on the basis of recorded documents without the aid of memory of the work done, the project documentation is excellent.

DATA ANALYSIS

Review of results should be conducted frequently. Supervisors should review progress often enough to keep the project on target. Studies such as filtration, coagulation, or lime softening may need daily or weekly review. Studies in which data are collected less frequently can be reviewed on a weekly or monthly basis. Slow sand filters, corrosion control studies, and column loading studies would usually fall in this category.

Major project reviews should be held periodically. These offer the opportunity to revise the plan of study based on results obtained to date. Failures can be abandoned, whereas successful treatment techniques can be refined and optimized.

The pilot plant operating staff members need to be alert for extreme conditions or unusual events that may present unique or special opportunities to do some testing that ordinarily might not be possible. Some examples are high or low turbidity or temperature, algal blooms, plant operating changes, changes in water demand, and repairs or modification to distribution system, such as removing a pipe for evaluation, or building in coupon insert locations where corrosion control tests can be performed in the future.

FINAL INTERPRETATION

After the study is completed, the data should be interpreted in the context of the total study as well as relevant literature or plant operating results if these are available. Assemble all of the data and consider the limitations of the data. The usefulness of data may be limited by minimum detectable values, or by precision of analytical methods. If this is the case, try to analyze data in a way not constrained by the above. Ask yourself if the results show a pattern that some reasonable theory or concept would support. Is the conclusion of your data analysis reasonable or wildly absurd? If the optimum pH for lime softening is below pH 7, or if coagulation studies show a zero dose of coagulant gave the best performance in a granular media filter, you may have serious problems. Although good pilot plant work may yield unexpected answers, no pilot plant results should repeal the law of gravity.

A variety of techniques can be used for data analysis. When a study is conducted to evaluate a treatment process intended to remove a contaminant listed in the Primary Drinking Water Regulations, attainment of the Maximum Contaminant Limit in the treated water is necessary. In this instance, actual concentrations of the contaminant before and after treatment would be shown in

tables and graphs. The MCL should be shown on graphs or stated in tables to aid in data interpretation.

When the performance of a process is evaluated, the percentage of change or removal may be graphed or tabulated to learn how the variables studied will affect the efficiency of the process. If a given range of influent concentrations has no effect on process efficiency, comparing removal percentages for influent concentrations in that range makes data analysis easier by stating all results on a common basis. In contrast, when actual concentrations of the substance are compared, variations of both influent and effluent must be graphed or tabulated in order to indicate process efficiency. In the absence of a defined water quality goal, percentage removal may be the preferred method of data analysis.

Some types of data, especially those related to raw water conditions, may be handled appropriately by use of probability graph paper. In these graphs, the cumulative probability of occurrence of an event is shown as the independent variable, and some water quality parameter such as turbidity, color, stream flow, bacteria count or algal count may be the dependent variable. Such graphs can be used to estimate the liklihood that certain water quality conditions might occur. Under some circumstances, probability graphs also may be used to analyze pilot plant effluent data. Some examples of all three types of graphs for data analysis are found in a recent paper on water filtration by Logsdon and Fox (3).

PROJECT REPORT AND RECOMMENDATIONS

Preparing the project report is frequently the last step of the pilot plant project. This phase of the activity draws upon the analysis and interpretation of data performed at the conclusion of the data collection phase. Pilot plant reports should be written clearly and in sufficient detail, with adequate graphs, charts, and photos to permit others to understand the results. The audience may include:

1. Higher level technical people

2. Administrators with little or no technical background

3. Citizens, water utility customers, the "guy who pays the bills"

Be prepared to communicate with any of the above, and with radio, TV, and newspapers if pilot plant work may lead to a construction project and large capital investment. The culmination of effort is implementing pilot plant findings full-scale. The engineer should, therefore, be skilled in communicating technical ideas to both technical and non-technical audiences. Communication skills are essential to successful pilot plant projects and to successful engineering careers.

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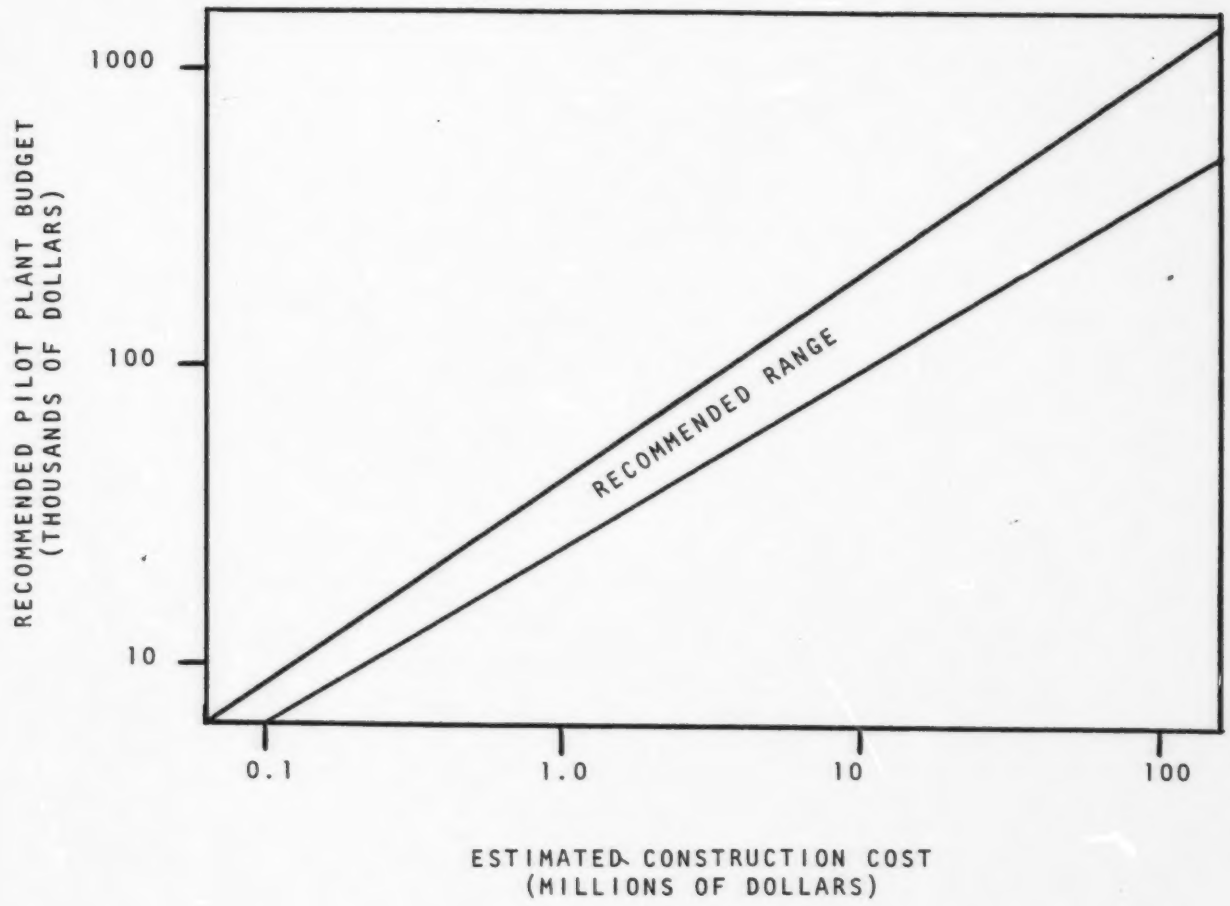

Fig. 1. PILOT PLANT BUDGET VS. CAPITAL COST (FROM TRUSSELL)